REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
		FINAL 01 AUG 92 TO 31 JUL 95

4. TITLE AND SUBTITLE
APPLICATION OF DIFFERENTIAL INVERSION TO DMSP MICROWAVE SOUNDER DATA

5. FUNDING NUMBERS
F49620-92-J-0444
2310/CS 61102F

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AFOSR-TR-96
0104

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NM
110 DUNCAN AVE, SUITE B115
BOLLING AFB, DC 20332-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-92-J-0444

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

See report for abstract

19960320 069

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

Application of Differential Inversion to

DMSP Microwave Sounder Data:

Final Progress Report on AFOSR Grant F49620-92-J-0444

by

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I. Results

Thus far the application of the Differential Inversion (DI) algorithm developed by Dr. Jean King formerly of Phillips Laboratory has not yielded satisfactory results for the inversion of DMSP SSM/T microwave data to atmospheric temperature profiles. The temperature profiles obtained to date show large, nonphysical excursions in the temperature as a function of height which may deviate by 10 K or more from the temperatures obtained by co-located radiosonde observations. The temperature profiles generated by DI algorithms in the most recent round of research have not improved significantly since the last interim report and the reader is referred to that report for examples of those temperature profiles. As presently implemented, DI has no utility as an operational retrieval algorithm.

This lack of success in the microwave spectral region should be contrasted with the good results obtained using DI in the infrared [King et al. 1989]. It is clear that the primary physical difference between these two spectral regions, from the standpoint of the DI algorithm, is that in the microwave spectral region, the ground is visible as a radiator with some poorly determined and highly variable emissivity. For the temperature retrievals in the infrared, the DI algorithm was applied as if an infinite optical depth atmosphere with a temperature of the ground was matched onto the lower boundary of the physical atmosphere. This was appropriate as the relevant infrared emissivities were almost all very close to unity.

The importance of the emissivity of the ground was understood at the beginning of this research, and an attempt was made to include and compensate for this problem by careful analysis of the DMSP SSM/T channels which intersected the ground, i.e. those channels for which the weight function had a substantial nonzero value at ground level. This effort was not successful, which we attribute partially to the intrinsic variability of those weight functions due to contributions from low-level atmospheric water vapor, and due to fundamental algorithmic issues discussed in §II below.

It must be carefully understood that the problem is not in the implementation of the DI algorithm including ground emissivity, per se. If good emissivity information were available by other means, DI could yield temperature profiles using microwave spectral data which are of comparable quality to the temperature profiles which have been obtained from TOVS data. However, (1) DI is very sensitive to badly-determined emissivity information, and (2) proper emissivity values cannot be obtained from SSM/T data alone.

II. Numerical Instability and Differential Inversion in the Microwave Band

The fundamental step in the implementation of the DI algorithm is the evaluation of the Planck function as a function of height using the Eddington-King formula. The temperature as a function of height is then obtained by inversion of the Planck formula for blackbody radiation. We usually write the Eddington-King formula in the form:

$$B(z) = \lambda_0 R(z) + \lambda_1 \frac{dR(z)}{dz} + \lambda_2 \frac{d^2R(z)}{dz^2} + \cdots \quad (1)$$

Here $B(z)$ is the (monochromatic) Planck function describing the upwelling radiance as a function of altitude, z, which is computed from the logarithm of pressure. The λ's are inversion coefficients computable from moments of the atmospheric weighting functions for the channels used in the measurements. Lastly, $R(z)$ is the radiance. The radiance as a function of altitude is interpreted in terms of the map between frequency and altitude generated by the weight function peaking heights (or some other measure of weight function locations, such as the mean value of the weight function).

As seen from the Eddington-King formula, DI depends fundamentally upon information on the radiance derivatives. Numerical differentiation is a notoriously dangerous undertaking (Acton 1970), though a best estimator of the derivative may be constructed using Vandermonde matrix techniques, (Isaacson and Keller 1966, Hohlfeld and Collins in preparation). The evaluation of a best estimator of the radiance derivative amounts to construction of a polynomial fit of the radiance data and using that fit to evaluate the radiance derivatives.

Including badly determined radiances from the ground (i.e. radiances based on an inaccurate determination of the emissivity of the ground) amounts to adding a bad radiance point at a low z value. This bad radiance point corrupts the polynomial fit and generates the oscillations of the fitting polynomial which are ultimately seen as nonphysical variation of the temperature as a function of height. The problem described here is further exacerbated because the order of the fit required (typically a fourth order fit) is not much less than the number of available channels (seven).

III. Prospects using a Multispectral Approach

The results discussed above make it clear that additional information will be required in order to effecively use DI for temperature retrievals in the microwave spectral region. Recently work on microwave emissivity determinations using SSM/I observations has been brought to our attention (Felde and Pickle 1995). This work has distinct promise for an independent determination of the surface emissivity which may be used to overcome the present difficulties with DI temperature profile retrievals. Effectively, this multispectral approach would add to the number of channels used in the temperature profile determination, which also would yield a more stable and physical result.

IV. Conclusions

Temperature profiles obtained by Differential Inversion (DI) applied to SSM/T data have unacceptably large deviations from co-located radiosonde observations. These deviations arise due to the small number of available SSM/T channels and from the requirement for well-determined surface emissivities, which have not been available heretofore. Recent results by Felde and Pickle on surface emissivity determination using SSM/I data suggest the possibility of using those surface emissivity determinations as part of the data input to DI. Such a multispectral approach to DI would retain DI's advantages of computational efficiency and direct connections to the physical content of the equation of radiative transfer.

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